

(NASA-Case-GSC-13562-1) LINEAR  
ENCODING DEVICE Patent Application  
(NASA) 22 p

N94-15703

Unclass

G3/61 0190826

NASA CASE NO. GSC 13,562-1

PRINT FIG. 1

NOTICE

The invention disclosed in this document resulted from research in aeronautical and space activities performed under programs of the National Aeronautics and Space Administration. The invention is owned by NASA and is, therefore, available for licensing in accordance with the NASA Patent Licensing Regulation (14 Code of Federal Regulations 1245.2).

To encourage commercial utilization of NASA-owned inventions, it is NASA policy to grant licenses to commercial concerns. Although NASA encourages nonexclusive licensing to promote competition and achieve the widest possible utilization, NASA will consider the granting of a limited exclusive license, pursuant to the NASA Patent Licensing Regulations, when such a license will provide the necessary incentive to the licensee to achieve early practical application of the invention.

Address inquiries and all applications for license for this invention to NASA Patent Counsel Goddard Space Flight Center Code 204  
Greenbelt, MD 20771

Approved NASA forms for application for nonexclusive or exclusive license are available from the above address.

Serial No.: 08/037,876  
Filing Date: 3/29/93

GSFC

## AWARDS DIGEST

**Linear Encoding Device**

The basic design for a new Linear Encoding Device is shown in FIG 1. This device, which will encode the linear displacement of a moving object 14 has a light source 2 emitting a light beam such that a light spot 6 is created on a linear array detector 4. An analog-to-digital converter 8 is connected to the linear array detector 4 for reading the position of the spot 6 on the linear array detector 4. A microprocessor 10 with memory is connected to the analog-to-digital converter 8 to hold and manipulate the data provided by the analog-to-digital converter 8 on the position of the spot 6 and to compute the position of moving object 14 based upon the data from the analog-to-digital converter 8.

Novelty is believed to reside in the utilization of a light source 2 to create a beam and produce a spot 6 on the detector 4 from which linear displacement information of moving object 14 can be obtained.

NASA Case No. GSC 13,562-1

Inventor: Douglas B. Leviton, Goddard Space Flight Center

Serial No.: 08037,876

Filing Date: 3/29/93

**PATENT**

NASA Case No. GSC 13,562-1

Application of: Douglas B. Leviton

TITLE OF THE INVENTION

Linear Encoding Device

Origin of the Invention

The invention described herein was made by an employee of the United States Government, and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

5

Technical Field

This invention relates generally to linear encoding devices and more particularly to an absolute linear encoding device with high sensitivity.

10

Cross Reference to Related Applications

This invention is related to an invention shown and described in U.S. Patent Application S/N 07/971,035, entitled "Rotary Encoding Device", filed in the name of Douglas B. Leviton on 11/03/92 and to U.S. Patent application S/N 08/022,219, entitled "Rotary Encoding Device", filed in the name of Douglas B. Leviton on 02/25/93. The above are assigned to

the assignee of the present invention.

### Background Art

Many scientific, industrial, aerospace, robotics, and military/weapons applications require  
5 precise and accurate knowledge of the transverse position in space of some object or  
machine part. Typically, this knowledge is provided by an optical, magnetic, or  
potentiometric encoder. Encoders of the highest practical precision are relative or  
incremental in nature, i.e. they could resolve very small changes in position and can keep  
10 track of accumulated change relative to some reference location, but the position  
information is lost if this reference becomes corrupted, as through power interruption or  
upset by electromagnetic interference. On the other hand, there are absolute encoders  
which provide position information which is independent of any reference (except of course  
its own calibration, hopefully traceable to some standards maintenance organization such  
as NIST -- formerly NBS). The absolute nature of these encoders is sometimes  
15 accompanied by only low to moderate sensitivity.

The subject of this disclosure is a simple, absolute, linear encoding scheme I have  
devised, whose operation relies on the direction or deflection of a light beam onto a linear  
charge-coupled-device (CCD) array. It can be retrofitted to mechanical systems where  
transverse position information is needed or as an upgrade to systems which already have  
20 linear encoders. It will rival state-of-the-art incremental and absolute encoders in spatial

resolution and can also be used to measure the magnitude of the vibration environment in which it is immersed along its measurement direction.

### Statement of the Invention

5 It is therefore an object of the present invention to provide a linear encoding device having high absolute accuracy

It is a further object of the present invention to provide a linear encoding device that is compact and reliable with state-of-the-art positional sensitivity.

10 Another object of the present invention is to provide a linear encoding device that is capable of operating at moderately high speed, that has redundancy attainable through additional read channels, and that provides vibration/jitter information available from computation of perturbed spot shapes.

15 These and other objects are achieved by providing a linear encoding device for position encoding in which the encoder's main benefits are derived from recent advances in linear array CCD technology where devices with small pixels numbering in the thousands have become readily available. The present inventive Linear Encoding Device in its simplest form is a small, mono- or poly-chromatic light source which moves with respect to a linear array CCD, where the array is aligned to the direction of motion. The position information is derived from the determination of the one dimensional centroid of a light pattern on the  
20 array. The information is acquired from the array with simple analog to digital (A/D)

conversion electronics connected to a microprocessor which computes the centroid spot location and thus determines position.

### Brief Description of the Drawings

5 Figure 1 is a view of the device geometry of the present inventive linear encoding device.

Figure 2 shows an offset misalignment of the light source to the array photodetector.

Figure 3 shows a shift misalignment of the light source to the array photodetector.

Figure 4 shows a separation misalignment of the light source to the array photodetector.

10 Figure 5 shows a twist misalignment of the light source to the array photodetector.

Figure 6 shows a wedge misalignment of the light source to the array photodetector.

Figure 7 shows a roll misalignment of the light source to the array photodetector.

Figure 8 is a graph of the mean error in determining spot locations.

Figure 9 is a graph of the standard deviation in determining spot locations.

15 Figure 10 is a first alternate embodiment of the linear encoding device.

Figure 11 is a second alternate embodiment of the linear encoding device.

Figure 12 is a third alternate embodiment of the linear encoding device.

Figure 13 is a fourth alternate embodiment of the linear encoding device.

Figure 14 is a fifth alternate embodiment of the linear encoding device.

20

### Detailed Description of the Invention

The encoder's main benefits are derived from recent advances in linear array CCD technology where devices with small pixels numbering in the thousands have become readily available. Referring now to Figure 1, the present inventive Linear Encoding Device in its simplest form is a small, mono- or poly-chromatic light source 2 (or pencil beam of light) which moves with respect to a linear array CCD 4, where array 4 is aligned to the direction of motion as shown. The position information is derived from the determination of the one dimensional centroid of light pattern 6 on array 4. The information is acquired from array 4 with simple analog to digital (A/D) conversion electronics 8 connected to a microprocessor 10 which computes the centroid spot location and thus determines position. Other forms of the encoder might include collimating and beam folding optics to accommodate packaging or environmental constraints.

### Operating Principle of Encoding Device

The geometry of the device is shown in figure 1. Array 4 is affixed to a stationary object 12 in the mechanical system and light source 2 travels with moving part 14 of the system whose position is desired to be encoded, or vice versa. The centroid of the invariant light pattern 6 on array 4 moves by exactly the same amount as moving part 14, and so the measurement of that centroid on array 4 is a direct measurement of the displacement of moving part 14.

Considerations for Device Accuracy

Small misalignments of array 4 to the direction of motion will have only small effects on accuracy (see figures 2, 3, 4, 5, 6, and 7 for alignment nomenclature). The nomenclature for the six degrees of freedom for alignment for light source 2 and array 4 and the  
5 magnitude of each misalignment on accuracy are as follows:

displacement: distance in the x direction to be measured

offset -- error in starting point in the x direction; direct error i.e. 1 for 1

shift: offset in the y direction transverse to direction of displacement but parallel to

10 array 4; negligible error -- centroid location unaffected

separation: distance in the z direction between light source 2 and array 4; negligible error -- centroid location unaffected

twist: rotation about the z axis manifesting itself in shift of light pattern 6 across array 4 with changing displacement; error proportional to cosine of twist angle with some  
15 associated offset

wedge: rotation about the y axis resulting in a change in separation with changing displacement and possibly manifested on array 4 as a spot whose width changes as a function of changing displacement but whose centroid would remain unaffected an error in scale proportional to the cosine of the wedge angle results and is generally negligible.

20 roll: rotation of array 4 about the x axis; negligible error -- centroid location



unaffected

It is interesting to note that three misalignments do not affect accuracy while the effects of the remaining three can be calibrated out.

## 5     **Performance**

Due to the ability to compute the centroid of the light distribution of spot 6 on pixel array 4, resolution can be extended well below the single pixel level. A simulation has been performed to study the array photodetector 4 subsystem's capabilities in this regard. The simulation accounts for the following effects: beam shape and size and irregularities therein,  
10 pixel-to-pixel photoresponse variation, system conversion noise, and repetitious sampling. In the simulation, a photoresponse for each array 4 pixel is chosen randomly within selectable, prescribed limits. A target location for a perfect Gaussian profile is randomly chosen to fall somewhere on array 4. Then, a Gaussian whose half-width is selectable but whose pixel value at each pixel is randomly perturbed by some noise factor within selected  
15 limits, is computed along with its effective centroid location and error relative to the foreknown target Gaussian center. If multiple samples have been specified, the average of that number of samples is considered to be the result. This is repeated one hundred times for each set of prescribed limits. Mean error, variance, and standard deviation are then computed for the one hundred samples.

20

The simulation was parameterized as follows. Three different Gaussian spot 6 sizes (diameters) were tried: 0.40 mm, 0.80 mm, and 1.6 mm diameters. Four different combinations of system noise and pixel-to-pixel variations were tried for each spot 6 size. With one exception, two different numbers of samples -- 1 and 3 -- were tried for each combination of system noise and pixel-to-pixel variation. The parameterization is tabulated below.

Table I -- parameters for simulation of spot location determination by array photodetector system for each of the three different spot sizes

System Noise (%)	Pixel-to-pixel Variation (%)	Samples
3	2	1
3	2	4
2	1	1
2	1	3
1	1	1
1	1	3
0.5	0.5	1
0.5	0.5	3

The results for mean error and standard deviation in pixels for single sample simulations are shown in figures 8 and 9 respectively. The results indicate the two obvious things one would expect: that performance improves for 1) lower system noise and lower pixel-to-pixel variation and 2) smaller spot 6 sizes. CCD experts at Eastman Kodak indicate that in practice, pixel-to-pixel variations and system noise can be systematically reduced to less than 0.5% each. This immediately focusses attention to the left-hand part of the figures. Even

for the largest spot 6 size studied, 1.6 mm Gaussian diameter, the mean error and standard deviation are astoundingly only several millipixels. To be conservative, I shall choose 0.005 pixels as an achievable number for centroided pixel resolution. This assumes one can get a spot 6 size under 1.6 mm diameter. Using a compact HeNe laser with an exit spot 6 diameter of 0.7 mm and a beam divergence of 1 mrad, the baseline design has a total path length roughly 0.4 m. This distance combines with the beam divergence to increase spot 6 size from 0.7 mm to  $0.7 + 400 \cdot 0.001 = 1.1$  mm which is well less than 1.6 mm.<sup>8</sup>

Assuming linear array photodetector 4 incorporates  $7 \mu\text{m}$  pixels, a positional resolution of  $0.005 \cdot 7 \mu\text{m} = 0.035 \mu\text{m}$  or 35 nm or 350 Å should be achievable (worst case).

This value compares favorably with the capabilities of the state-of-the-art, laser ranging interferometer system which has a resolution of 0.2 to 1 μinches or  $\approx 50$  to 250 Å. However, laser ranging interferometers are incremental devices.

#### Alternate Embodiments

Figures 10 - 14 show alternate embodiments of the invention. In Fig. 10, light source 2 is removed from moving part 14 and guided in by fiber optic 16 through a slit 18. In Fig. 11, a low divergence laser beam is guided through slit 18 by flat fold mirror 20. In Fig. 12, the slit is removed and the low divergence laser beam is aimed on linear array CCD 4 by flat fold mirror 20. In Fig. 13, light source 2 emits a beam which first passes through pinhole 22 then collimating lens 24 and then is guided by flat fold mirror 20 through slit 18 to CCD 4. In Fig. 14, the slit is removed and replaced by a reimaging lens 26.

**Other Considerations**

Regarding vibration, it is entirely possible that the encoding device could also be used to give information about the vibration environment in which it is used. This would be done either through time-averaged or even time-resolved computations on spot 6 shape  
5 perturbations measured from linear array 4.

To those skilled in the art, many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that the present invention can be practiced otherwise than as specifically described herein and still will be within the spirit and scope of the appended claims.

### ABSTRACT

A Linear Motion Encoding device for measuring the linear motion of a moving object is disclosed in which a light source is mounted on the moving object and a position sensitive detector such as a array photodetector is mounted on a nearby stationary object. The light source emits a light beam directed towards the array photodetector such that a light spot is created on the array. An analog-to-digital converter, connected to the array photodetector is used for reading the position of the spot on the array photodetector. A microprocessor and memory is connected to the analog-to-digital converter to hold and manipulate data provided by the analog-to-digital converter on the position of the spot and to compute the linear displacement of the moving object based upon the data from the analog-to-digital converter.

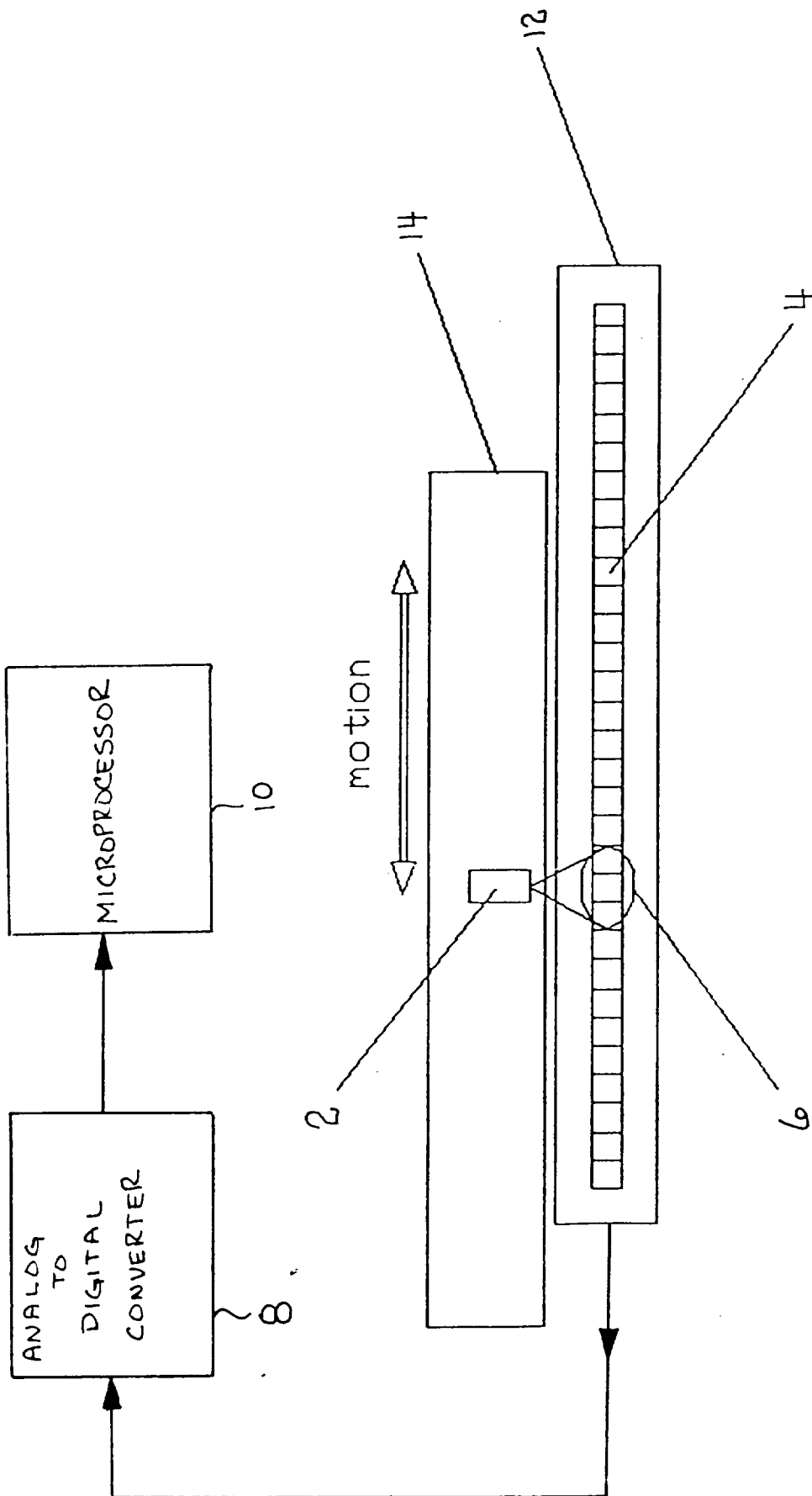
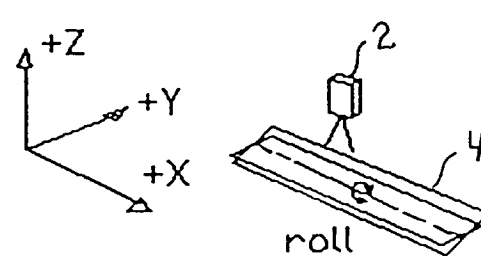
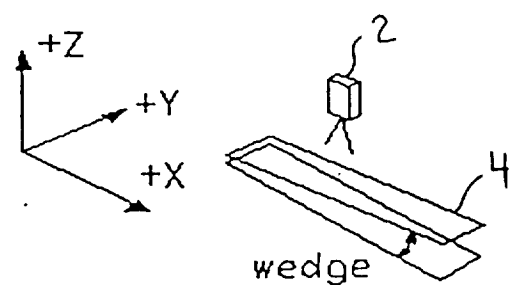
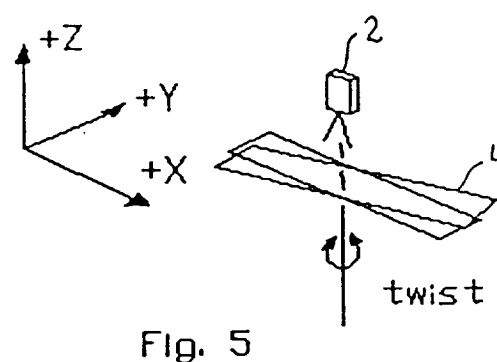
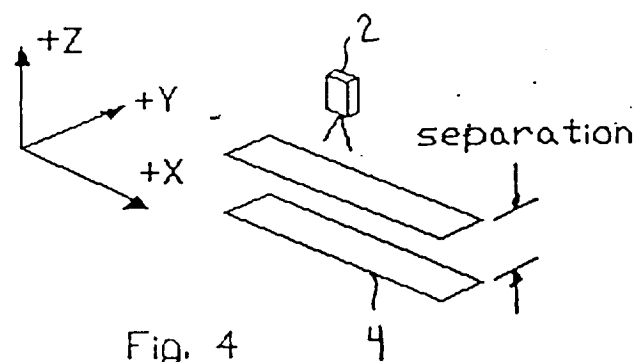
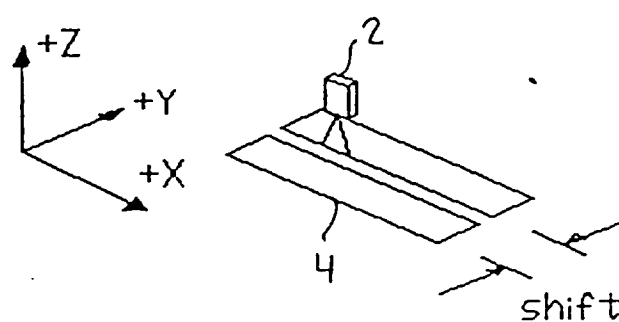
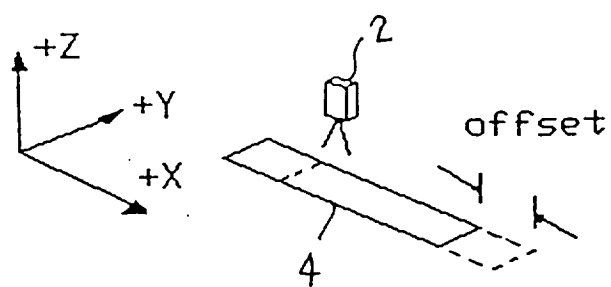
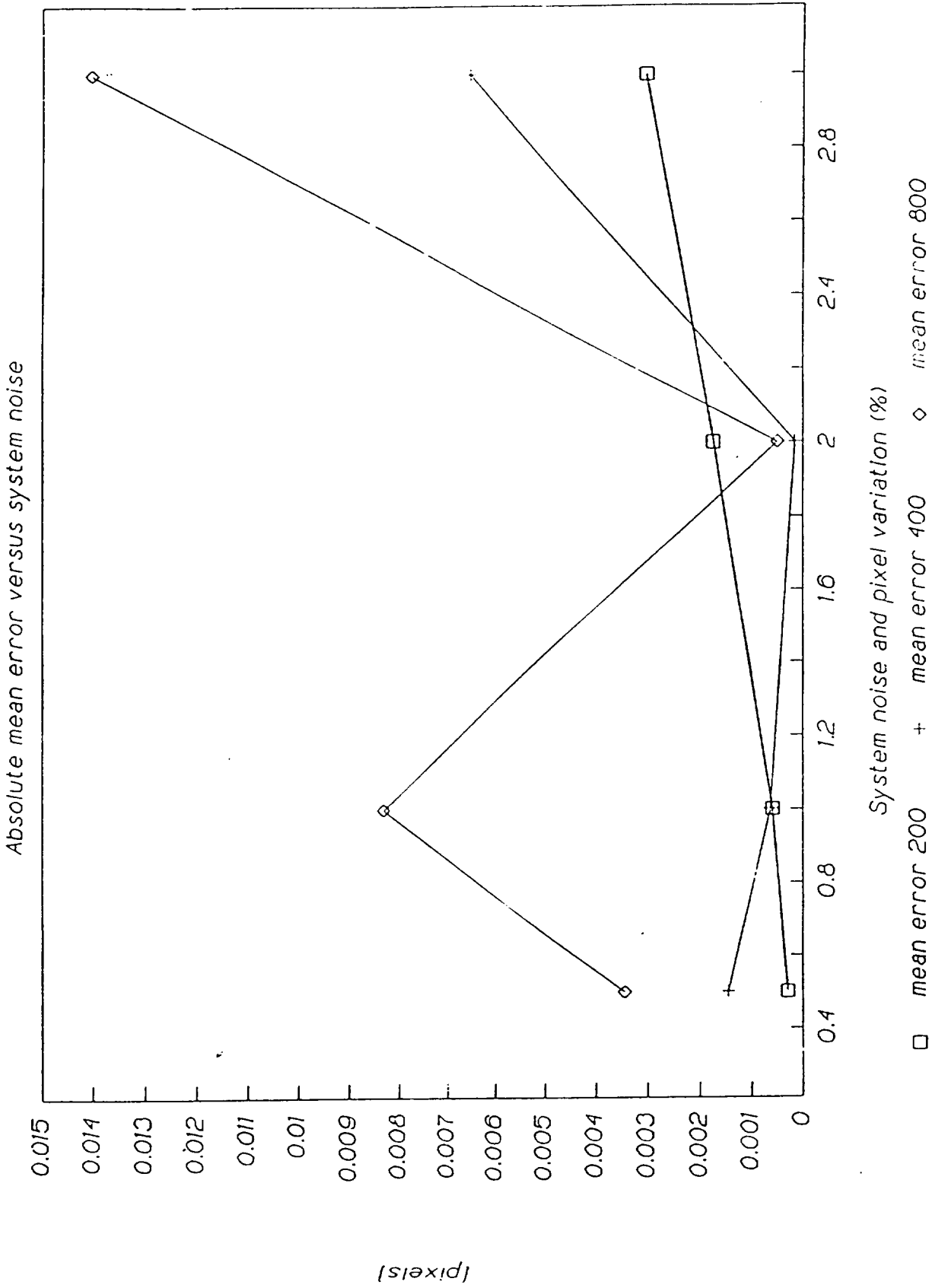


Fig. 1



# Centroid Gaussian Spots on Linear Array



for three Gaussian beam radii ( $\mu\text{m}$ )

Figure 8



# Centroid Gaussian Spots on Linear Array

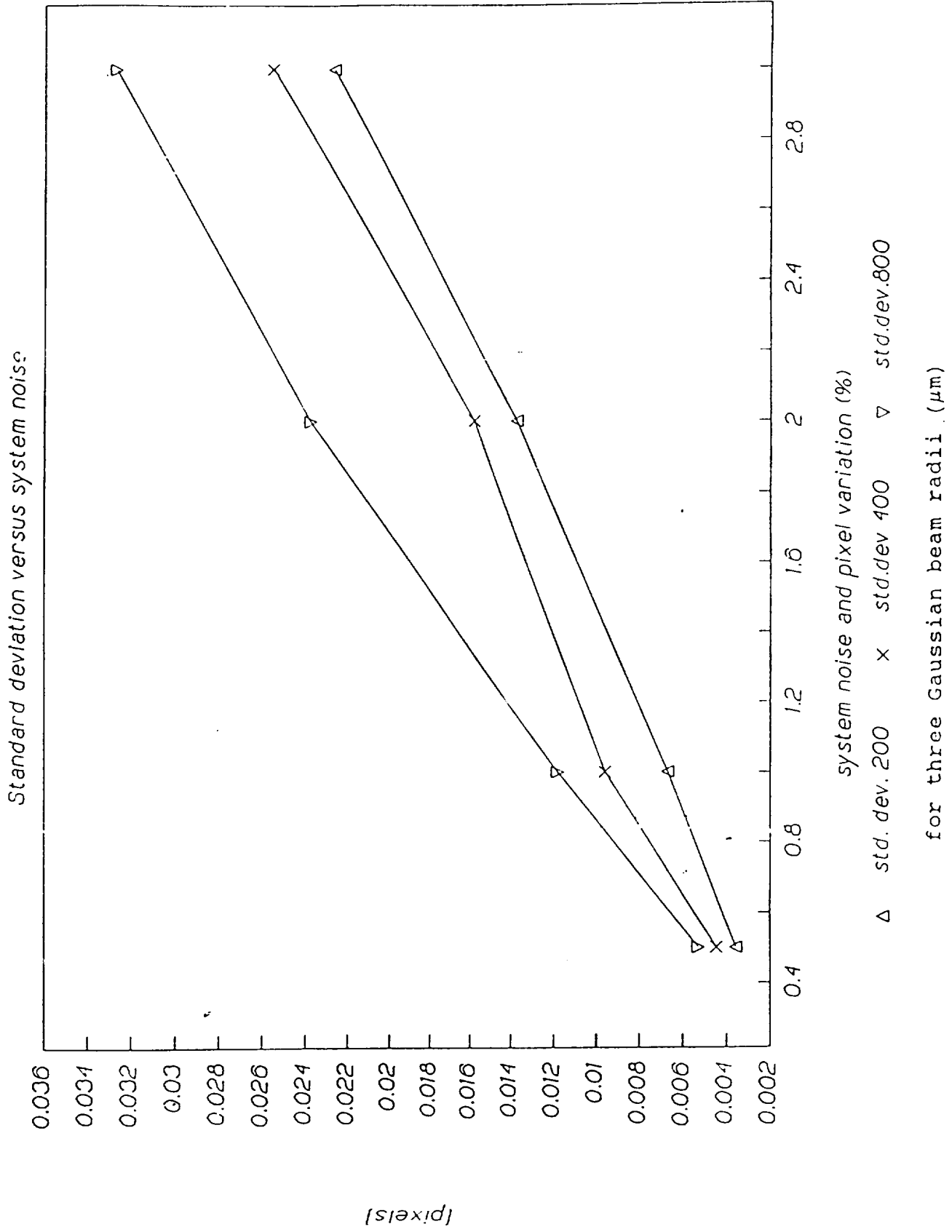


Figure 9

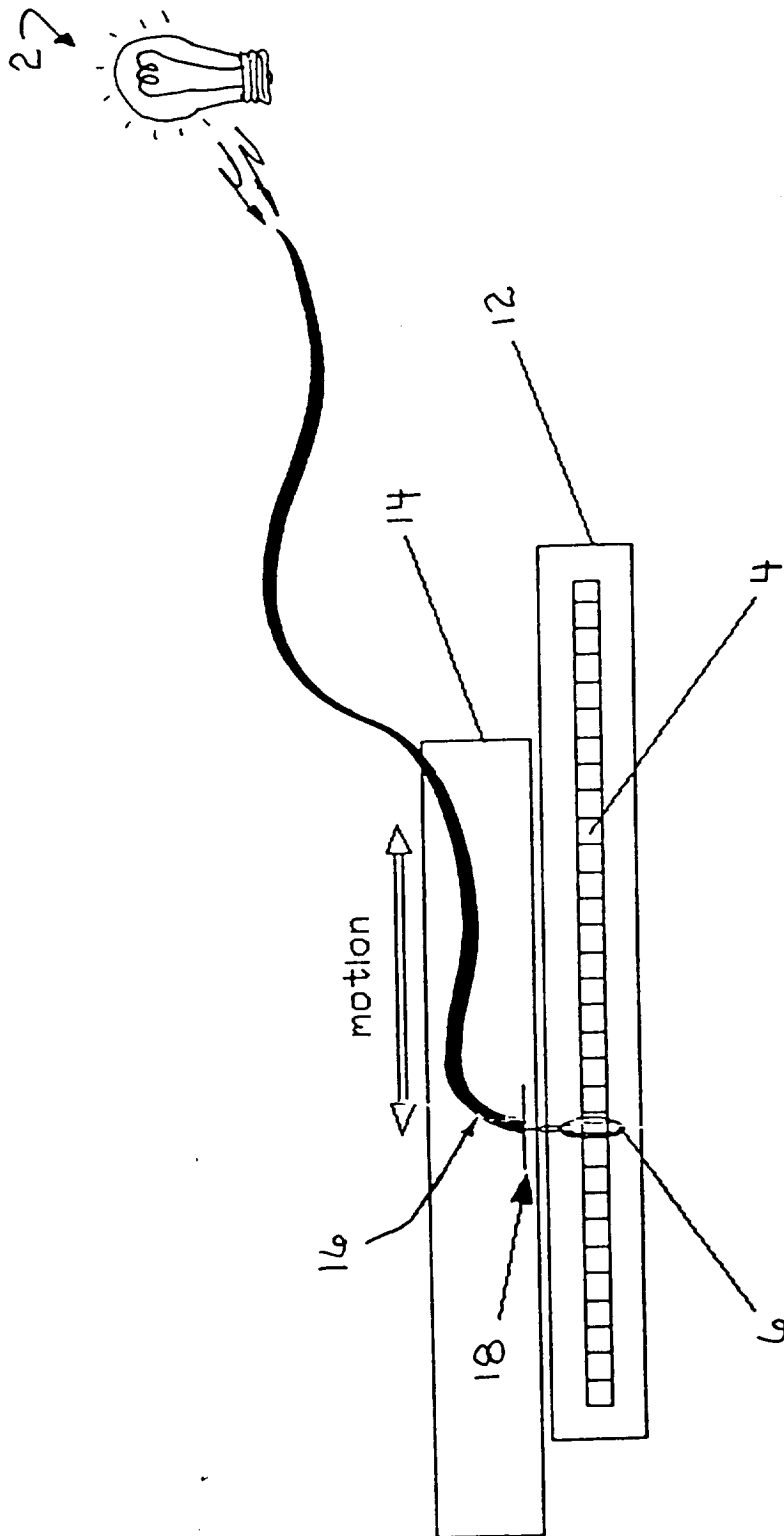


FIG. 10

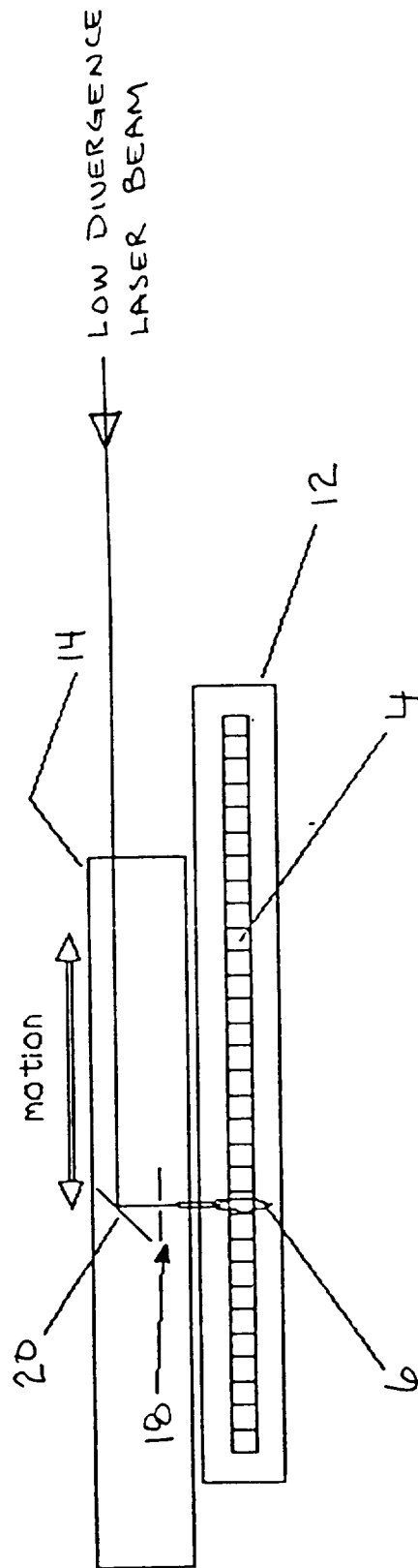


FIG. 11

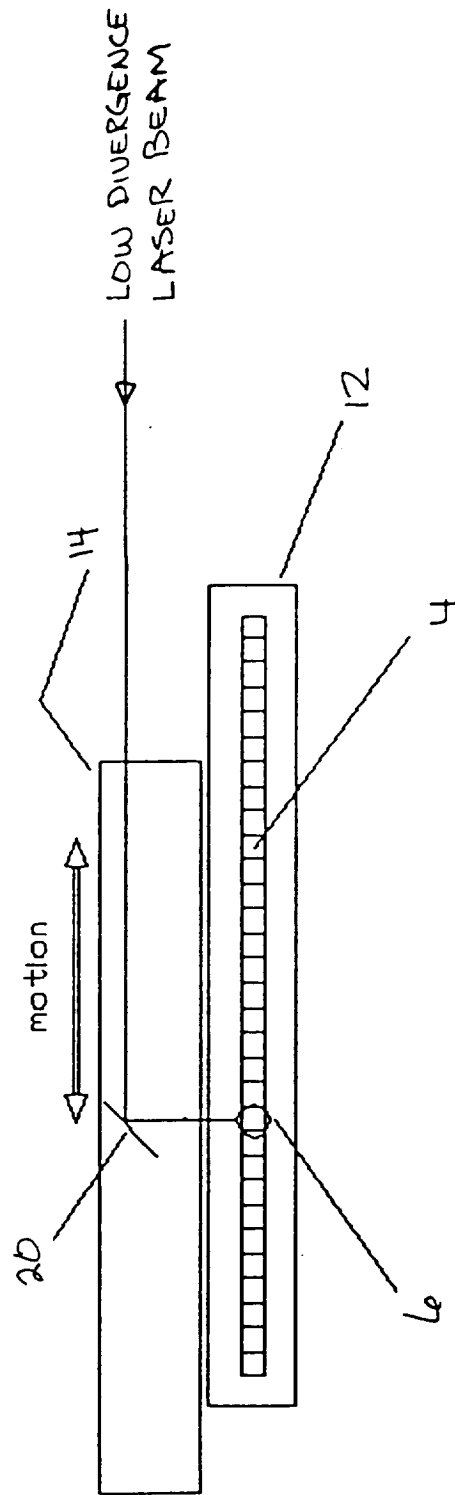


FIG. 12

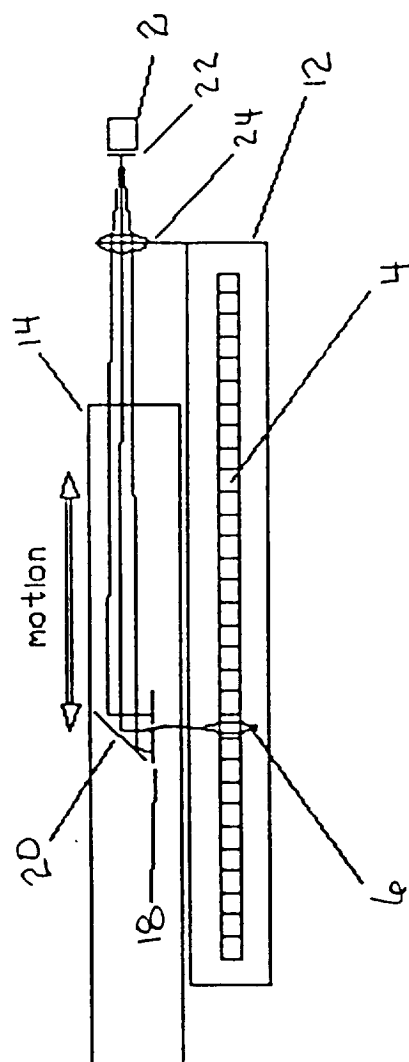


FIG. 13

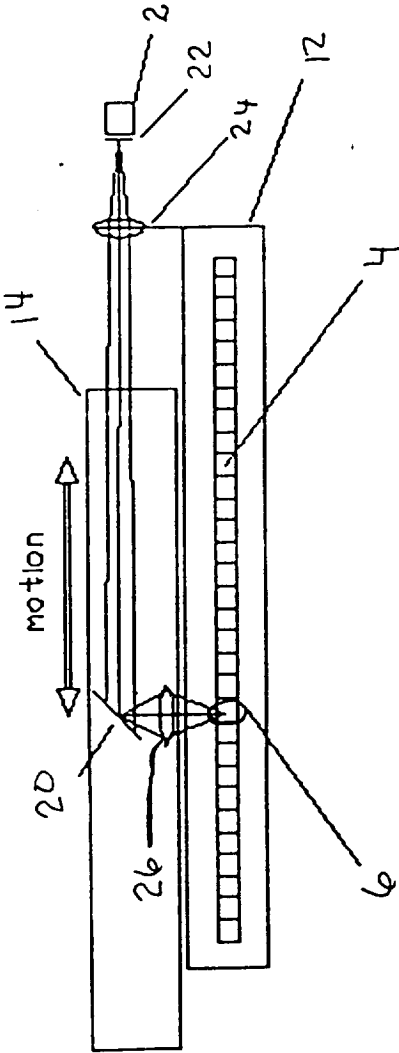


FIG. 14